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(58) Field of Search

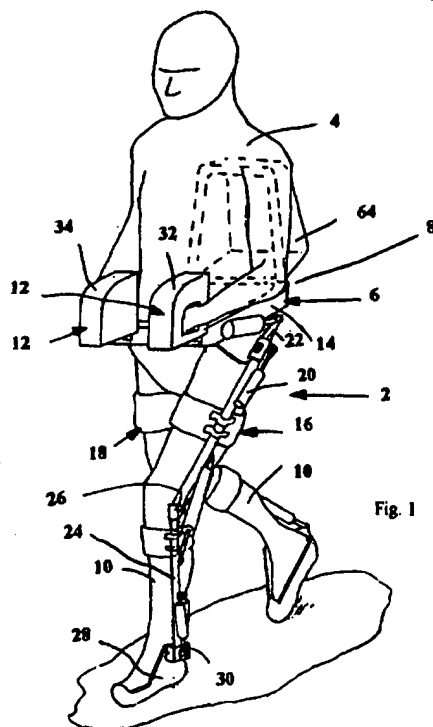
UK CL (Edition O ) A5R RFA RFB

INT CL<sup>6</sup> A61F 2/60 5/01 5/058

ONLINE: WPI, CLAIMS, JAPIO

(54) Walking aid with control means

(57) Apparatus 2 for helping persons 4 to walk, an orthosis, comprises an exoskeleton 6 for wearing around a body part 8 and legs 10 and control means 12 for operating the device 6. The exoskeleton 6 comprises a body section 14 and first and second leg sections 16, 18, which in turn comprise thigh portions 20, hip joints 22, knee joints 26, shin portions 24, ankle joints 30 and foot portions 28. Each leg section is controlled by an individual control means which preferably comprises a joy stick configured in a shape similar to the leg section. On movement of the joy stick signals are transduced to the leg section to produce similar movements to those effected on the joy stick. Movements are compensated for by negative feedback control.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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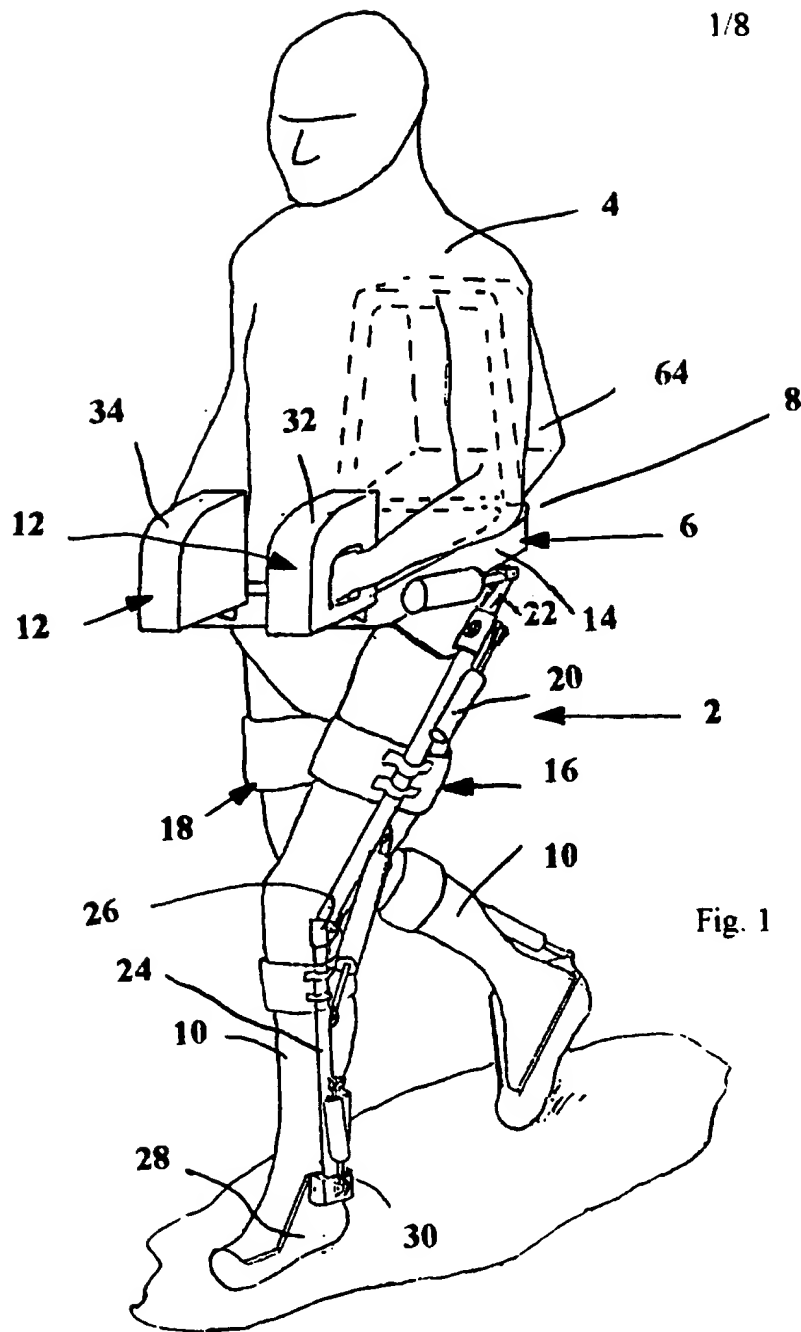


Fig. 1

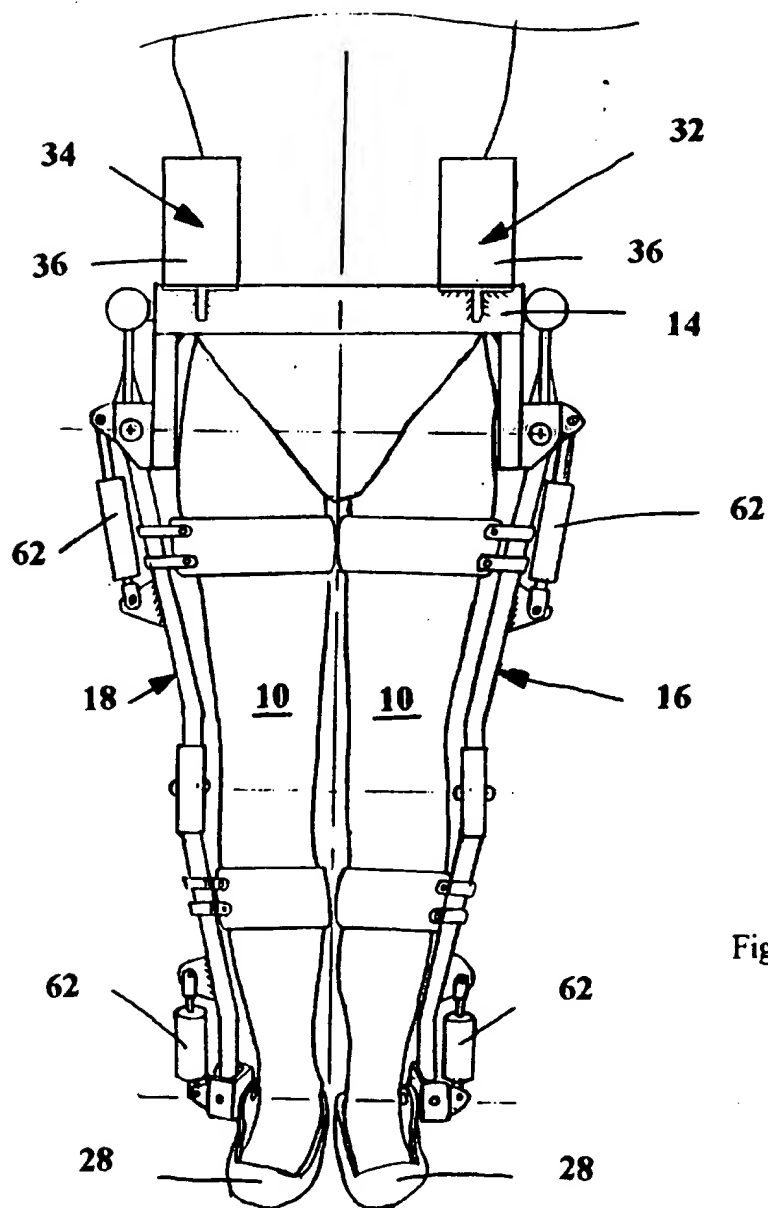
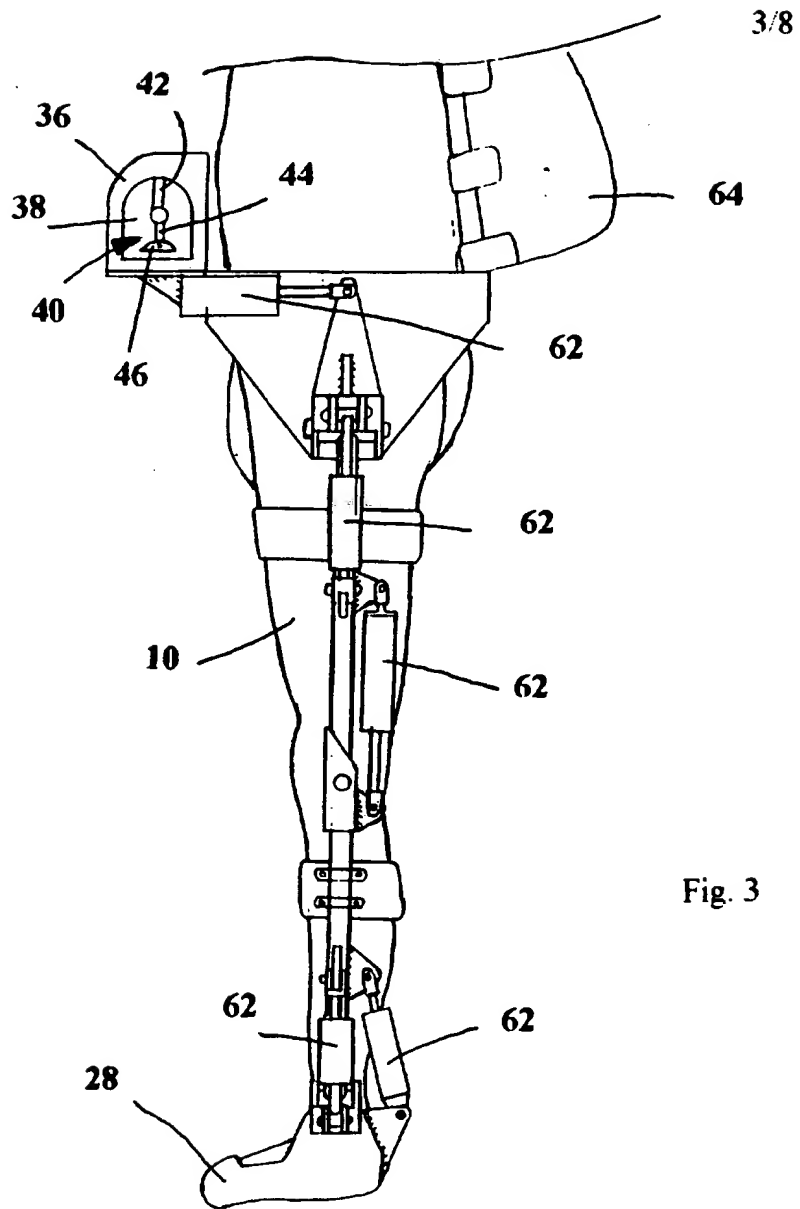
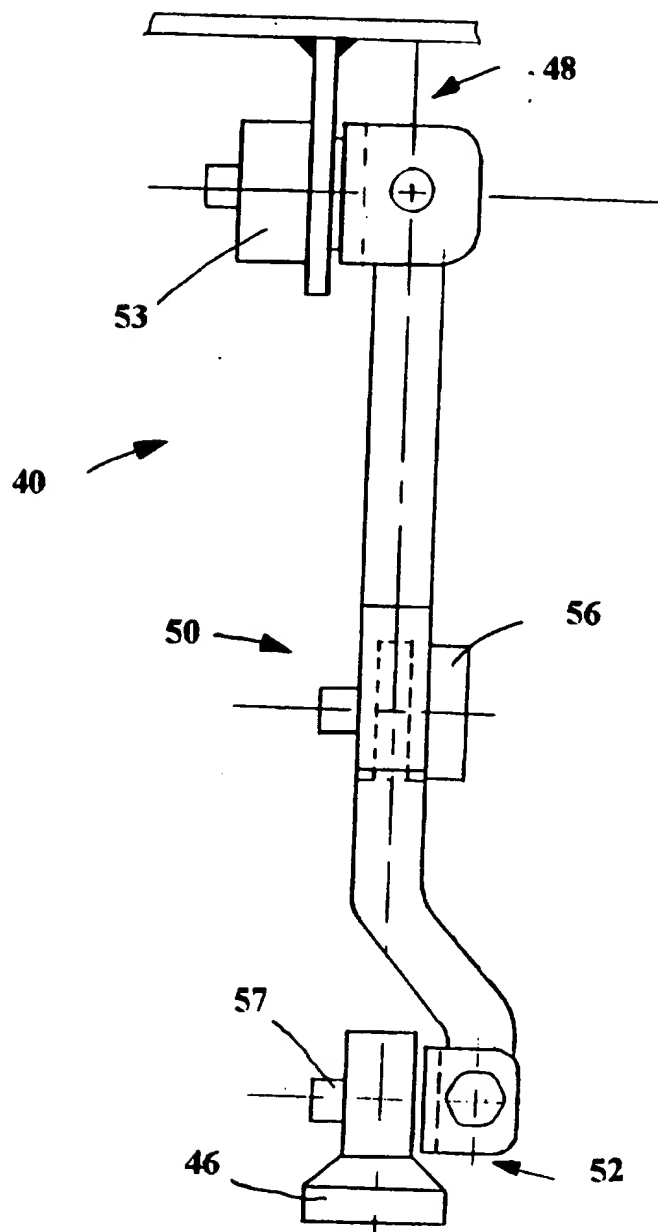


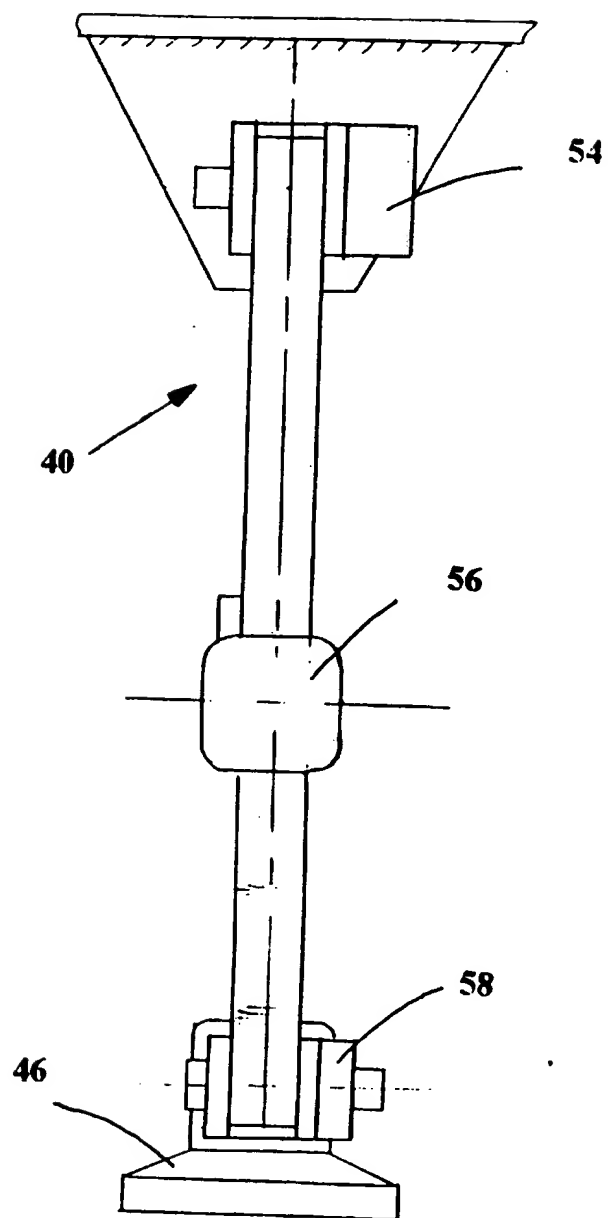
Fig. 2





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Fig. 4



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Fig. 5

Fig 6

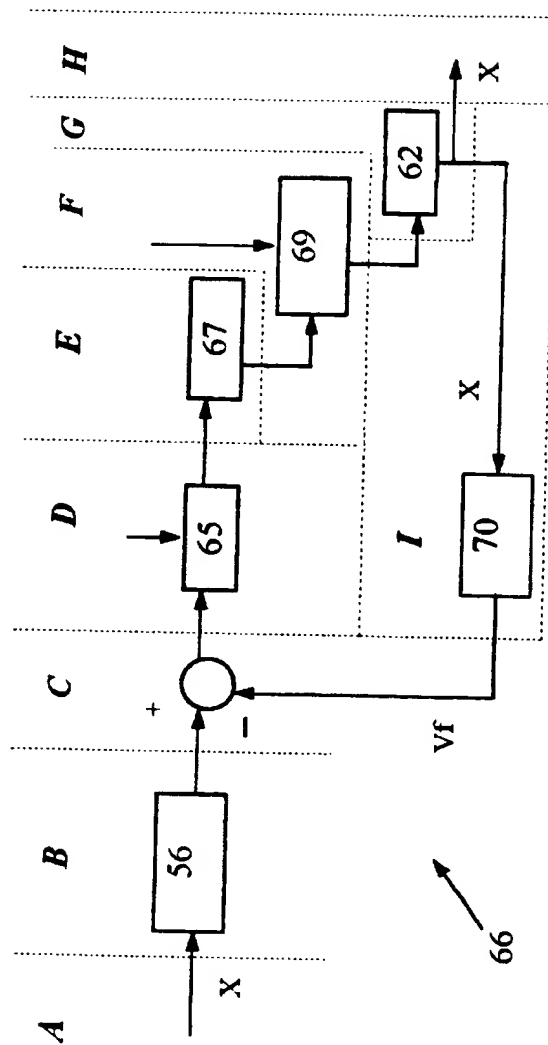
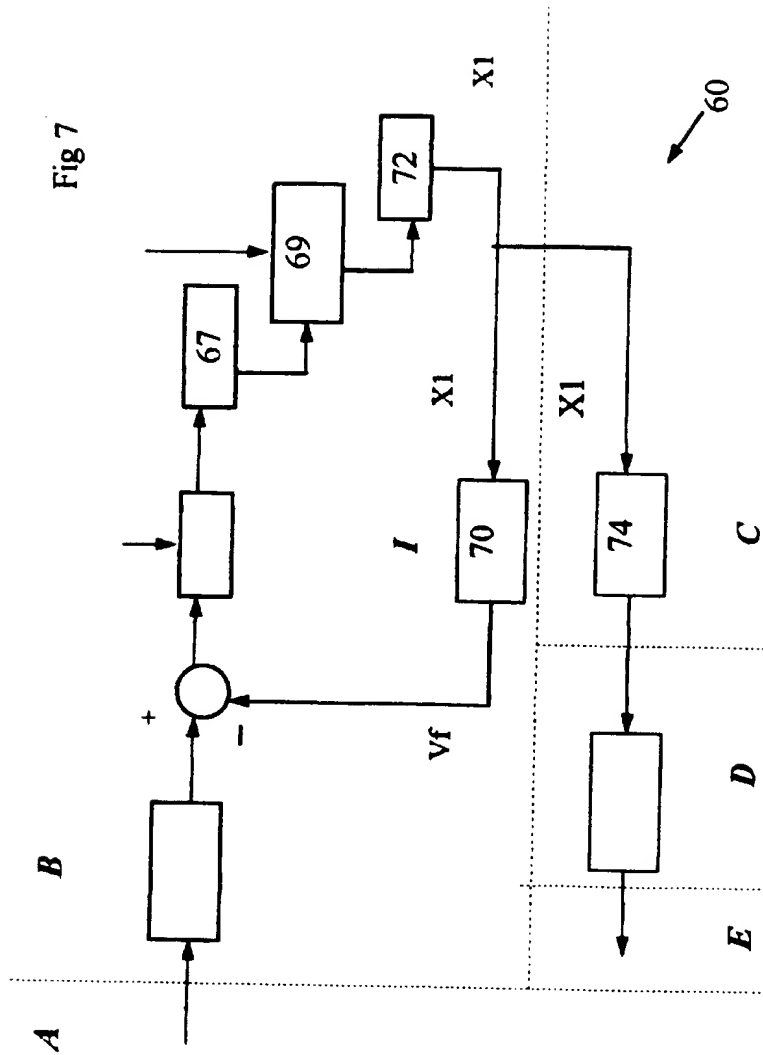


Fig 7





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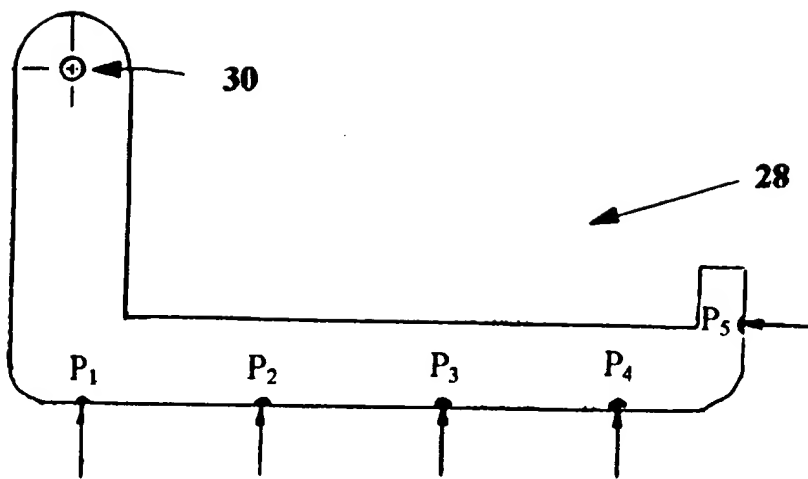


Fig. 8

APPARATUS FOR HELPING PERSONS TO WALK

This invention relates to apparatus for helping persons to walk.

There are many persons who are for a variety of reasons unable to walk or to walk as well as they would wish in their given circumstances. For example, paraplegics are generally unable to walk at all. Persons without their legs and who are sufficiently agile can sometimes walk with artificial legs but trouble may be encountered in trying to emulate a normal walking action. Other persons without legs are not sufficiently agile and/or strong to be able to walk with artificial legs. There are other people who have extremely limited use of their legs and who can perhaps walk for one or two steps but cannot walk much further.

All of the above mentioned disadvantaged persons would benefit from an easy to use apparatus helping them to walk. It is an aim of the present invention to provide such apparatus.

Accordingly, in one non-limiting embodiment of the present invention there is provided apparatus for helping persons to walk, which apparatus comprises an exoskeleton for being worn around a body part and legs of a person, and control means for controlling the

operation of the exoskeleton: the exoskeleton being such that it comprises a body section and first and second leg sections, with each leg section comprising a thigh portion, a hip joint, a shin portion, a knee joint, a foot portion and an ankle joint; and the control means being such that it comprises first master-slave control means for the first leg section and second master-slave control means for the second leg section, with the first and the second master-slave control means each being such that it is movable by a hand of a person, and with the first and the second master-slave control means each being such that its movements cause similar movements to be effected by its leg section, whereby the person is able to control the operation of the first and the second leg sections by movements made by the person to the respective first and second master-slave control means.

The apparatus of the present invention is thus able to be used such that the hands of the person wearing the apparatus are able to control the movement of the leg sections and therefore their legs, whether their legs be their own legs or false legs. This hand control of the apparatus of the invention enables the person to walk more naturally and with more spontaneity than is the case with many known types of apparatus for helping a person to walk.

The exoskeleton may be worn around any suitable and appropriate body part of the person, for example the waist and/or the torso. Thus the body section may be a waist section and/or a torso section.

Preferably, the apparatus is one in which the first and the second master-slave control means each comprise a joystick having a first portion for moving the thigh portion of the exoskeleton, a second portion for moving the shin portion of the exoskeleton, and a third portion for moving the foot portion of the exoskeleton.

Preferably, the joysticks are each in the same shape as the first and the second leg sections, whereby the person is able to move a chosen part of the leg sections simply by moving the same shaped part on the joystick. Thus the two joysticks are preferably scaled down versions of the first and the second leg sections. The first and the second master-slave control means may be other than joysticks if required so that they may be, for example, any suitable and appropriate transducer arrangements. Generally, the first and the second master-slave control means can each be of any design that operates such that an input to it by a hand of the person wearing the apparatus of the invention is output as a movement desired by the person in the leg sections. The advantage of using joysticks in the shape of the leg sections is that a chosen movement in a joystick is able

to be mirrored by its leg section, thus providing a very simple and easy way for a person wearing the apparatus of the invention to use the apparatus.

The apparatus may be such that the first and the second master-slave control means each comprises a negative feedback control system for each type of movement (i.e. each degree of freedom of movement) in each joint. A negative feedback control system may give precision and smoothness of movement of the leg sections.

The apparatus of the invention may also include a force feedback arrangement enabling a force encountered by the first and the second leg sections to be felt by a hand of the person on the master-slave control means. Thus a person may be able to feel through their hands when the leg sections have encountered an obstacle or something. Without such feel, a leg section of the apparatus could snag on an obstacle, and the tendency would then be for the person wearing the apparatus of the invention to apply more force to that leg section via the master-slave control means in order to try and get the leg section to move. If however the leg section is unable to move due to being snagged on an obstacle, the result would be to cause an imbalance in the apparatus of the invention which is desirably avoided.

The force feedback arrangement may include force transducers in the leg sections. The force transducers may be, for example, in the foot portions of the leg sections.

The force transducers can send appropriate signals via another negative feedback control system to apply a braking force at the appropriate joint or joints of each joystick in order to create at the fingers of the user, the impression of countering an obstacle. There are no brakes on the exoskeleton. The braking force is automatically applied to the joint or joints of the joysticks to thus feed back the forces experienced by the legs of the exoskeleton, to the fingers of the user.

The apparatus of the invention may include actuators for moving the thigh, shin and foot portions of the leg sections. Usually there will be one of the actuators for each type of movement (i.e. each degree of freedom of movement) permitted by one of the portions of the leg sections.

The actuators are preferably pneumatically or hydraulically operated actuators. Electrically operated actuators may also be employed.

The apparatus of the invention can be used by persons to supplement their use of a wheelchair, and to enable the persons to walk for enjoyment and recreational use.

An embodiment of the invention will now be described solely by way of example and with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a person wearing apparatus for helping the person to walk;

Figure 2 is a front view of the apparatus shown in Figure 1;

Figure 3 is a side view of the apparatus shown in Figure 1;

Figure 4 is a front view of a joystick forming part of a master-slave control means, a force feedback system being omitted for ease of illustration.

Figure 5 is a side view of a joystick shown in Figure 4;

Figure 6 shows the layout of a negative feedback control system forming part of the master-slave control means;

Figure 7 shows a force feedback arrangement forming part of the apparatus of the invention; and

Figure 8 shows schematically a foot portion of an exoskeleton forming part of the apparatus of the invention.

Referring to Figure 1, there is shown apparatus 2 for use in helping a person 4 to walk. The apparatus 2 comprises an exoskeleton 6 which is worn around a waist

8 and legs 10 of the person 4, and control means 12 for controlling the operation of the exoskeleton 6.

The exoskeleton 6 is such that it comprises a waist section 14, a first leg section 16 for one leg 10, and a second leg section 18 for the other leg 10. Each leg section 16, 18 comprises a thigh portion 20, a hip joint 22, a shin portion 24, a knee joint 26, a foot portion 28 and an ankle joint 30.

The control means 12 is such that it comprises first master-slave control means 32 for the first leg section 16, and second master-slave control means 34 for the second leg section 18. The first and the second master-slave control means 32, 34 are each such that they are movable by a hand of the person 4, as is shown somewhat schematically in Figure 1. The first and the second master-slave control means 32, 34 are also each such that its movements cause similar movements to be effected by its leg section 16, 18. Thus the person 4 is able to control the operation of the first and the second leg sections 16, 18 by movements made by the person 4 with their hands to the respective first and second master-slave control means 32, 34.

Figures 2 - 5 show the first master-slave control means 32 in more detail. The second master-slave control means 34 is the same as the first master-slave control means 32. As can be seen from Figures 2 - 5,



the first master-slave control means 32 comprises a housing 36 having an aperture 38 for receiving a hand of the person 4. The housing 36 contains a joystick 40. The joystick 40 is a scaled down model of the first leg section 16. Thus the joystick 40 has a first portion 42 which looks like the thigh portion 20, a second portion 44 which looks like the shin portion 24, and a third portion 46 which looks like the foot portion 28. As can best be seen from Figures 3, 4 and 5, the joystick 40 also comprises a first joint 48 which is the same as the hip joint 22, a second joint 50 which is the same as the knee joint 26, and a third joint 52 which is the same as the ankle joint 30. Because the joystick 40 is of the same general shape as the first leg section 16, it is very easy for the person 4 to move an appropriate part of the joystick 40 and to get a mirrored movement in the appropriate portion of the first leg section 16.

Figures 4 and 5 also show how the joystick 40 has two transducers 53, 54, for each universal hip joint, one transducer 56 for each knee joint, and two transducers 57, 58 for each ankle joint. These transducers 53, 54, 56, 57, 58 are used in separate negative feedback control systems 66 as shown in Figure 6. In this way the movements of these joints can be translated into electrical signals and sent to the correct negative feedback control system which controls

the corresponding actuator and thus also the corresponding leg section.

Figures 2 and 3 show how the first and the second leg sections 16, 18 include actuators in the form of ram devices 62 for moving the thigh, shin and foot portions 20, 24, 28 of the leg sections 16, 18. As can be seen, there are two of the ram devices 62 for each hip and ankle joint, these hip and ankle joints being universal joints with two degrees of freedom of movement. The knee joint only has one ram and one degree of freedom of movement. In Figure 3, it will be seen that the first and the second leg sections 16, 18 each have two of the ram devices 62 for moving the ankle joint 30. This is to enable the foot portion 28 to move up and down and from side to side in the manner of a person's actual foot. In other words the two ram devices 62 used for the ankle joint 30 give the foot portion 28 movement in two planes.

It should also be noted from Figure 3 that two of the ram devices 62 are used for each hip joint 22. Again the two ram devices 62 enable the person's leg 10 to move in two planes. Only one of the ram devices 62 is required for the knee joint 26 since a knee joint normally bends only in one way.

Figures 1 and 3 show how the apparatus 2 is provided with a back pack 64 which contains a power

source for providing power to the apparatus 2. The back pack 64 also contains most of the components of the hydraulic system which supplies power to the ram devices. Any suitable and appropriate back pack may be employed. Thus, for example the back pack 64 may have an internal combustion engine as the power source. The internal combustion engine may be driven by petrol, butane, propane or any other suitable and appropriate fuel. Alternatively, the back pack 64 may derive its power from compressed gas, for example compressed air or compressed carbon dioxide stored in a container. Preferably the back pack 64 will be chosen to be quiet in operation but sufficiently powerful to power the apparatus 2. Batteries of an acceptable weight will generally not be able to provide enough power although batteries can be used if desired. Where the apparatus 2 is to be used indoors, then the back pack 64 should be such that it does not give off obnoxious fumes.

Referring now to Figure 6, there is shown a closed loop negative feedback control system 66. There is one of the control systems 66 for each ram device. The control systems 66 enable the first and second leg sections 16, 18 precisely to follow the movements of their respective joysticks 40.

Figure 6 will now be further explained considering the knee joint 26 of the first leg section 16, the knee

joint 26 of the second leg section 18 being such as to work in the same manner.

Figure 6 shows how the relative movement between the thigh portion 20 and the shin portion 24 of the exoskeleton 6 can be achieved. For this purpose Figure 6 has been divided up into sections labelled A to I. Each section is explained hereinbelow.

A. The person 4 moves the third portion 46 of the joystick 40 (corresponding to the foot portion 28 of the first leg section 16) in such a way as to cause the shin of the joystick 40 to move, relatively to the thigh of the joystick 40, about the knee joint of the knee. By this means, an input is made to the apparatus 2.

B. The relative movement is picked up by position transducer 56, and a signal  $V_i$  is sent. The signal  $V_i$  is not proportional to the magnitude of any given movement but the signal  $V_i$  is proportional to the angle of the joint. Thus changes in the signal  $V_i$  would be proportional to changes in the angle of the joint as would be caused by movements of the shin and thigh parts of the joystick.

C. An electronic circuit subtracts the feedback signal  $V_f$  from the input signal  $V_i$  to produce an error signal  $V_e$ .

D. The error signal  $V_e$  is amplified by an amplifier 65 to produce an amplified signal  $AV_e$ .

E. The amplified signal AVE is supplied to a controller 67. The controller 67 sends the signal to the correct end of a proportional valve 69, depending upon the sign of the signal, positive or negative. The proportional valve is a spool valve (or other valve) with a solenoid at each end. Thus, if the amplified signal AVE is positive, the spool valve moves one way, and if the amplified signal AVE is negative the spool valve moves the other way. Springs return the spool valve to a neutral portion when  $AVE = 0$ . In this way, the direction of the pressurised fluid is controlled. The flow rate of the fluid is dependent upon the extent to which the valve opens and this is proportional in magnitude to the amplified signal AVE.

F. The movement  $X_1$  of the core of one of the solenoids operates the spool valve (or other valve) which supplies pressurised fluid to a ram device 62.

G. The ram device 62, for example a double acting hydraulic ram, extends or contracts according to the sign of the error signal  $V_e$  (positive or negative). The ram device 62 also extends or contracts by an amount proportional to the magnitude of the error signal  $V_e$ . The extension or contraction is denoted by  $X$ .

H. The ram device 62 causes relative movement between the thigh portion 20 and the shin portion 24 of the exoskeleton 6. This is an output and it corresponds

in magnitude and direction to the input movement between the thigh (first portion 42) and the shin (second portion 46) of the joystick 40.

I. The output relative movement is picked up by a position transducer 70 located on the knee of the leg of the exoskeleton 6. The position transducer 70 sends a feedback signal to the electronic circuit mentioned at Section C above.

The control system 66 shown in Figure 6 operates to achieve a balance between the position transducers 56 and 70. This is achieved when  $V_i - V_f = 0$ , i.e. when  $V_e = 0$  and the ram device 62 is not moved. In this way, movements of the joysticks 40 and their respective first and second leg sections 16, 18 are synchronised.

Each of the ram devices 62 (or other suitable and desired actuators) has one of the control systems 66.

The balancing action of the control system 66 as shown in Figure 6 is rapid such that the movement of the ram device 62 appears to the person 4 to be smooth and continuous.

Referring now to Figure 7, there is shown a force feedback arrangement 60. The force feedback arrangement 60 is for ease of control of the first and second leg sections 16, 18. More specifically, the force feedback arrangement 60 enables forces encountered by the first and the second leg sections 16, 18, for example the foot

portions 28, to be conveyed back to the hands of the person 4 via the joystick 40. Figure 7 is specific to forces from the foot portions 28 but forces from other parts of the leg sections 16, 18 can similarly be transferred back and they have not been described in Figure 7 in order to avoid undue complication. The foot portion 28 of the first and second leg section 16, 18 might need the force feedback if the foot portion 28 were snagged upon an obstacle such for example as a fallen branch. Without the force feedback, the apparatus 2 would feel clumsy and numb to the person 4 and the person 4 would be unaware of any obstacles that had been collided with.

Figure 7 shows how the forces on the sole of the foot portion 28 of the first leg section 16 are fed back to the fingers of the person 4. Figure 7 has been divided up into sections A to E and each section is described hereinbelow.

A. An input to the force feedback arrangement 60 is achieved by pressure on the foot portion 28. Different pressures will act at different points on the foot portion 28. For simplicity these different pressures can be treated as isolated forces acting perpendicularly to the sole of the foot portion 28. It is these forces which are fed back to the joystick 40.

The actual force fed back is a single force which is representative of all the forces.

B. This is a negative feedback automatic controlled arrangement which produces a movement of an actuator 72. The movement may be regarded as being proportionally in magnitude to the overall pressure on the foot. It will be appreciated that it is not the movement of the actuator 72 which is important but the position of the actuator 72, that is the amount by which it is extended. The extension of the actuator 72 should be proportional to  $V_i$ . If  $V_i$  were to be half of  $V_{i\text{-max}}$ , then the actuator 72 would extend to half its maximum, etc.

C. Movement of the actuator 72 compresses a spring 74. The spring 74 may be coil spring or an air spring.

D. The compressed spring 74 exerts a force which operates brakes on all or some of the joints of the relevant joystick 40.

E. The output of the force feedback arrangement 60 is thus felt as a resistance to movement in the joints of the joystick 40. This is felt by the fingers of the person 4 and corresponds in magnitude to the forces acting on the foot portion 28 of the exoskeleton 6.



Referring now to Figure 8, there is shown a schematic representation of the foot portion 28. The foot portion 28 has transducers P1, P2, P3, P4 and P5 producing signals V1, V2, V3, V4 and V5 respectively. These signals are proportional to the pressure exerted upon the transducers P1, P2, P3, P4 and P5.

The transducers P1 - P4 are for the detection of weight and exertion, that is the load borne by the foot portion 28. The transducer P5 is for detecting collisions with obstacles.

The input to the force feedback arrangement 60 shown in Figure 7 is Vi. This is a summation of all the outputs of the transducers V1 - V5, that is Vi equals  $V1 + V2 + V3 + V4 + V5$ .

Most of the time, the transducer V5 will be zero as the foot portion 28 will normally not be engaging obstacles.

The distribution of the transducers P1 - P4 over the sole of the foot portion 28 should be such as to ensure that Vi remains constant for a constant load upon the foot portion 28. In other words, if a given load were evenly to be distributed over the sole of the foot portion 28, each transducer P1 - P4 might output, for example, 10mV. Thus  $V_i = V1 + V2 + V3 + V4 = 40mV$  ( $V5 = 0$ ). If then the ground became uneven, it might happen that the same load would then be borne by only

part of the foot portion 28, for example the part where transducer P2 is located. In this case,  $V_1$ ,  $V_3$  and  $V_4 = 0$  and  $V_5 = 0$ .  $V_2$  would be expected to be close to 40mV. Thus  $V_i$  would remain constant for a constant load upon the foot portion 28. The more transducers used, then the more accurately is  $V_i$  able to represent the total load on the sole of the foot portion 28.

The output from the transducer P5 is larger than the outputs from other transducers P1 - P4. The outputs from the other transducers P1 - P4 are used to restrict the movement of the joystick 40 and thus to simulate forces felt upon the foot portions 28 of the leg sections 16, 18. These forces are forces of weight and exertion. However, the larger output from the transducer P5 is used to virtually halt the joystick 40, as indeed a collision with an obstacle would tend to halt the movement of the exoskeleton 6 and the person 4.

It is to be appreciated that the embodiment of the invention described above with reference to the accompanying drawings has been given by way of example only and that modifications may be effected. Thus, for example, the exoskeleton can be worn around the torso of the person 4 as an alternative or in addition to the waist 8. Actuators other than ram devices may be employed. The apparatus may be pneumatically or

electrically driven, instead of being hydraulically driven as illustrated.

**CLAIMS**

1. Apparatus for helping persons to walk, which apparatus comprises an exoskeleton for being worn around a body part and legs of a person, and control means for controlling the operation of the exoskeleton: the exoskeleton being such that it comprises a body section and first and second leg sections, with each leg section comprising a thigh portion, a hip joint, a shin portion, a knee joint, a foot portion and an ankle joint; and the control means being such that it comprises first master-slave control means for the first leg section and second master-slave control means for the second leg section, with the first and the second master-slave control means each being such that it is movable by a hand of a person, and with the first and the second master-slave control means each being such that its movements cause similar movements to be effected by its leg section, whereby the person is able to control the operation of the first and the second leg sections by movements made by the person to the respective first and second master-slave control means.

2. Apparatus according to claim 1 in which the first and the second master-slave control means each comprise a joystick having a first portion for moving the thigh

portion of the exoskeleton, a second portion for moving the shin portion of the exoskeleton, and the third portion for moving the foot portion of the exoskeleton.

3. Apparatus according to claim 2 in which the joysticks are each in the same shape as the first and the second leg sections, whereby the person is able to move a chosen part of the leg sections simply by moving the same shaped part on the joystick.

4. Apparatus according to any one of the preceding claims in which the first and the second master-slave control means each comprise a negative feedback control system for each type of movement in each joint.

5. Apparatus according to any one of the preceding claims and including a force feedback arrangement enabling a force encountered by the first and the second leg sections to be felt by a hand of the person on the master-slave control means.

6. Apparatus according to claim 5 in which the force feedback arrangement includes force transducers in the leg sections.

7. Apparatus according to claim 6 in which the force transducers are in the foot portions of the leg sections.

8. Apparatus according to claim 6 or claim 7 in which the force transducers are such that they send appropriate signals via another negative feedback control system to apply a braking force at the appropriate joint or joints of each joystick in order to create at the fingers of the user, the impression of encountering an obstacle.

9. Apparatus according to any one of the preceding claims and including actuators for moving the thigh, shin and foot portions of the leg sections.

10. Apparatus according to claim 9 in which the actuators are pneumatically or hydraulically operated actuators.

11. Apparatus for helping persons to walk, substantially as herein described with reference to the accompanying drawings.



# The Patent Office

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**Application No:** GB 9611885.6  
**Claims searched:** 1-11

**Examiner:** Dr J Houlihan  
**Date of search:** 3 September 1996

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): A5R RFA, RFB

Int Cl (Ed.6): A61F 2/60, 5/01, 5/058

Other: ONLINE: WPI, CLAIMS, JAPIO

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2206494 (HUGH STEEPER LTD.) page 6 line 4-page 7 line 14; Figures 1,2 & 17	
A	US 5020790 (BEARD J E <i>et. al.</i> ) column 2 lines 40-61; Figures 1-3	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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